AGE AND SEX DIFFERENCES IN SIZE OF SHARP-SHINNED HAWKS

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The Goshawk (*Accipiter gentilis*), the largest and least sexually dimorphic member of the genus in North America (Storer, 1966), shows an increase in wing length and weight and a decrease in tail length in the year that elapses between the juvenal plumage and the first adult plumage (Mueller et al., 1976). This paper establishes similar, and additional changes in size with age for the Sharp-shinned Hawk (*A. striatus*), the smallest and most sexually dimorphic member of the genus occurring in North America. We discuss the probable functions of this age dimorphism. We also present criteria that will permit more critical determination of the age and sex of Sharp-shinned Hawks.

We trapped almost 2,000 Sharp-shinned Hawks in the autumns of 1953 through 1964 at the Cedar Grove Ornithological Station on the western shore of Lake Michigan about 70 km north of Milwaukee, Wisconsin. Due to occasional errors, not all measurements were recorded for all birds, and the sample sizes vary slightly. An additional 42 birds were trapped in the springs of 1954 through 1957 and 1962 through 1965.

A description of the Cedar Grove region can be found in Mueller and Berger (1966). The trapping methods used are described by Bub (1974) and measuring techniques are given in Mueller et al. (1976). A description of the migrations of Sharp-shinned Hawks at Cedar Grove is given in Mueller and Berger (1967).

AGE CRITERIA

A bird entirely in the brown (juvenal) plumage is a juvenile or HY-SY (Hatching Year until 31 December, Second Year after 1 January). The entire dorsal surface, including the head, back, wings and tail are brown and the underside is whitish with brown streaks. We trapped one juvenile in May that showed a few adult feathers on the back; we suspect these feathers were accidentally lost and replaced rather than normally molted. The molt from the juvenal plumage into the first adult (basic) plumage is usually not completed until summer or early fall of the second year.

Adults are gray above, and the feathers of the underside are whitish, heavily barred with a reddish-brown. In autumn, a largely adult-plumaged bird with any brown feathers is an adult I or SY (between one and two years old). We have not trapped an adult-plumaged bird in spring that showed any trace of the juvenal plumage, suggesting that postjuvenal molt is completed before spring.

An entirely adult-plumaged bird with two generations of feathers (feathers produced by two different molts presumably in two different years) is an adult II (more than two years old) or ASY-ATY (after second year-after third year). We trapped only one bird in spring that could be assigned to this age category.

An adult-plumaged bird with only one generation of feathers is an adult of unknown age or AHY. The age of some of these individuals can be determined by eye color (see below).

Extremely careful examination of the bird, in good light, is necessary to distinguish ASY from AHY. Each flight feather (remex and rectrix) should be examined closely for differences in wear and coloration. Feathers of a previous generation usually show noticeably more wear on the tips, particularly in the rectrices, and a subtle fading in coloration is sometimes apparent. Adult Sharp-shins often do not show molt that permits assignment of the bird to adult I or II, and differences in feather wear and color can be extremely subtle. We aged only 45% of the adult females and 36% of the adult males. Molt of Sharp-shins takes several months, and feathers molted early (e.g., innermost primaries) may show more wear than feathers molted later (outermost primaries). A bird with new innermost primaries and faded, worn (and gray) outermost primaries can thus be assigned to adult II. Molt of the secondaries is complex and somewhat irregular, proceeding in both directions from several foci. Molt of the rectrices is also somewhat erratic, beginning with the central (no. 1) and outer (no. 6) pairs and usually ending with no. 2 or 5. The presence of a few feathers of another generation, particularly in the body plumage, may not be the result of a molt because feathers pulled out in an accident are replaced without delay by feathers of the next plumage. We found molt on only three of the adults trapped in spring and only one of these could be aged.

Eye color of Sharp-shins changes with age, progressing from gray to pale yellow, orange, red, and finally a very dark red. The color change shows considerable individual variation but generally occurs more rapidly in males than in females. All juveniles in autumn had irides of varying shades of yellow, very rarely with some gray. We subjectively assigned the eye color of each adult to one of six categories. These are listed below, along with *approximate* equivalents from Smithe (1975): light orange (color 18, orange yellow of Smithe), orange (17, spectrum orange), dark orange (16, chrome orange), light red (15, flame scarlet), red (14, scarlet), dark red (11, spectrum red). Table 1 shows the incidence of these colors of known adult I and adult II Sharp-shins trapped in autumn. Birds with irides colored dark orange or the various shades of red can be definitely assigned to adult II. Only 21% of our sample fell into this category. Birds with light orange or orange irides cannot be safely aged. We recorded the eye color of six juvenile males trapped in spring; all had light orange irides. Three of the four juvenile females for which we have records also had orange irides and the remaining one had yellow eyes.

Roberts (1967) was able to age 63% of adult Sharp-shins (47% were adult I) by carefully comparing iris color with 35 colors in the color atlas of Villalobos-Dominguez and Villalobos (1947). Unfortunately, this at-

TABLE 1.
Iris color in adult Sharp-shinned Hawks.[1]

	N	Light orange	Orange	Dark orange	Light red	Red	Dark red
Adult I male	103	96	4	0	0	0	0
Adult I female	196	97	3	0	0	0	0
Adult II male	103	10	24	10	14	23	19
Adult II female	114	23	41	11	6	10	9

[1] The number given is the percentage of that age and sex class which is of that color.

las, and similar ones, are extremely expensive and many are also out of print. The only cheap and readily available atlas is that of Smithe (1975), and although it would improve accuracy of eye color determinations, it contains too few colors to permit successful separation of adult I birds by iris color alone, and would not increase our percentage of adult II birds that can be aged by iris color.

SEX CRITERIA

Sex of birds was determined by an examination of the distributions of measurements as explained in detail by Mueller et al. (1976). The measurements are presented in Table 2 and sex criteria, with confidence limits, in Table 3. Data from adult I, adult II, and adult of unknown age are grouped in these tables because most birds were simply aged as

TABLE 2.
Autumn measurements of Sharp-shinned Hawks.[1]

		Males		Females	
Measurement	Age	N	Mean ± SD (Range)	N	Mean ± SD (Range)
Tail length (mm)	Juv.	494	134 ± 3.8 (121–144)	548	158 ± 4.2 (146–174)
	Adult	440	132 ± 4.0 (115–143)	492	156 ± 4.4 (144–175)
Wing chord (mm)	Juv.	493	169 ± 3.7 (158–182)	544	200 ± 4.4 (183–213)
	Adult	437	171 ± 3.5 (161–182)	489	203 ± 4.3 (192–217)
Weight (g)	Juv.	489	98 ± 5.8 (80–116)	522	166 ± 10.3 (125–197)
	Adult	435	103 ± 6.4 (82–125)	487	174 ± 10.4 (144–208)

[1] Within each age class, males differ significantly from females in every measurement (*t*-test, $P < 0.0001$). Within each sex, adults differ significantly from juveniles in every measurement (*t*-test, $P < 0.0001$).

TABLE 3.
Sexing criteria and confidence intervals.

Measurement	Age	Confidence interval (%)	Upper limit for males	Lower limit for females
Tail length (mm)	Juv.	99.62	144	145
	Adult	99.50	143	144
Wing chord (mm)	Juv.	99.99	182	183
	Adult	99.99	185	186
Weight (g)	Juv.	>99.99	121	122
	Adult	>99.99	130	131

adult and because there is no significant difference in any measurement between the two groups of adults. Either tail length, wing chord, or weight can be used to determine the sex of a Sharp-shin with near certainty, with weight being, very slightly, the best indicator and tail length the worst. In the Goshawk exactly the opposite is true, with tail allowing sexing with a confidence of 98.2 to 99.5% and weight with a confidence of only 79 to 90% (Mueller et al., 1976). Wing chord is of intermediate certainty as an indicator of sex in both species.

CHANGES IN SIZE WITH AGE

Adult Sharp-shins have longer wings, shorter tails, and weigh more than juveniles (Table 2). All of these differences are highly significant (*t*-test, $P < 0.0001$). We found the same differences in the Goshawk and suggested that they would give an adult an advantage over a juvenile in intraspecific encounters and in the pursuit and capture of prey (Mueller et al., 1976). In our paper on Goshawks, we argued that the increase in wing length and weight were the results of increases in the size of each individual, and did not reflect greater survival of larger birds. Our limited sample of Sharp-shins trapped in spring offers some support for this argument (Tables 4, 5). One would expect that most mortality of juveniles occurs before spring migration. It is thus reassuring to find that juveniles trapped in spring were about the same size as those caught in fall, although they are slightly heavier. The difference in weight is not significant, and its possible importance is questioned by the fact that adult females are significantly heavier in spring than in autumn. The small sample creates doubt about any other possible conclusions; data for adult males strongly suggest that at least this sample taken in spring is aberrant. The spring adult males have significantly shorter tails and are almost significantly lighter in weight than those taken in autumn.

Some further support for our contention that individuals increase in size with age is provided by data from the three individuals that we retrapped slightly more than one year after they were first captured as juveniles. The two males showed increases in wing length of 4 and 5 mm

TABLE 4.
Spring measurements of Sharp-shinned Hawks.

Measurement	Age	Males N	Males Mean ± SD (Range)	Females N	Females Mean ± SD (Range)
Tail length (mm)	Juv.	8	133 ± 4.2 (125–138)	7	158 ± 5.7 (149–165)
	Adult	9	130 ± 2.8 (124–133)	18	156 ± 4.0 (149–163)
Wing chord (mm)	Juv.	8	168 ± 5.0 (161–175)	7	199 ± 5.0 (192–207)
	Adult	9	170 ± 3.3 (167–177)	18	202 ± 2.9 (199–208)
Weight (g)	Juv.	8	101 ± 8.2 (89–117)	7	173 ± 11.1 (158–189)
	Adult	9	99 ± 5.9 (87–107)	18	183 ± 9.3 (172–199)[1]

[1] Adult females are significantly heavier than juvenile females (t-test, $P < 0.04$).

and decreases in tail length of 2 and 8 mm. One individual weighed exactly the same in both years and the other lost 2 g. The female gained 3 mm in wing length, lost 2 mm in tail length, and gained 10 g. We also retrapped one male 2 years and 21 days after we banded it as a juvenile. It showed an increase in wing chord of 5 mm, a decrease in tail length of 5 mm and an increase in weight of 9 g.

The difference in weight between adults and juveniles does not appear to be due to differential fat deposition. In 1974, Berger examined 97 female Sharp-shins for the presence of subcutaneous fat in the axilla. (Biopsy samples were taken for chlorinated hydrocarbon analyses.) The incidence of fat in the two age classes was not significantly different: 29% of 58 juveniles had fat, 28% of 39 adults had fat (chi-square = 0.01, $P > 0.97$). Sharp-shins increase in weight as the fall progresses, and since the peak of the movement of adults is about a month later than that of the juveniles, the difference in weight might be largely attributable to the differences in season. We have calculated regression lines of weight and wing chord on calendar date for each age class; the picture is sufficiently complex that we are carrying out further analyses on a larger sample and will present the data in a separate paper. Within each age class, weight increases through the season but wing chord also increases. The cube root of the weight increase is less than the increase in wing chord.

Wing chord is generally regarded as a reasonable index of body size, and therefore the size of birds, within each sex and age class, appears to be increasing as the season progresses. Weight of a bird is a function of the cube root of a linear dimension. The fact that the cube root of

TABLE 5.
Comparisons of spring and autumn measurements.[1]

	Difference	Percent	P^2
Tail (mm)			
Juv. male	−1.48	−1.10	0.27
Juv. female	−0.08	−0.05	0.99
Adult male	−2.68	−2.02	0.05
Adult female	−0.12	−0.08	0.92
Wing chord (mm)			
Juv. male	+3.00	+3.07	0.16
Juv. female	+7.49	+4.52	0.06
Adult male	−4.00	−3.89	0.07
Adult female	+8.71	+5.00	0.0005
Weight (g)			
Juv. male	−0.99	−0.59	0.44
Juv. female	−0.93	−0.46	0.58
Adult male	−1.26	−0.74	0.29
Adult female	−0.35	−0.17	0.75

[1] +, spring values higher; −, autumn values higher.
[2] Probability of the difference arising by chance is just less than that given, *t*-test.

weight of each sex and age class does not increase as rapidly as wing chord as the season progresses suggests that the larger, late-season birds are *proportionally lighter* in weight than the smaller, early-season birds.

Weight apparently does not increase as the season progresses, and adults are no fatter than juveniles. We suggest that the difference in weight between juveniles and adults is due to increases in the size of flight muscles in the adults.

Wing loading helps to give an indication of flight speed, maneuverability, and other flight characteristics. Wing area can be estimated by the formula: wing area = (wing chord/0.62)^2/1.93 (Greenewalt, 1962). However, we believe that adult Sharp-shins have narrower, as well as longer wings than juveniles, and thus this formula probably overestimates the wing area of adults relative to that of juveniles. We are just beginning to measure wing area and wing dimensions on birds of prey and it will be some time before we have sufficient data, hence the use of estimates in the paper. The estimates show that females have considerably higher wing loading values than males and that adults have heavier wing loading values than juveniles (Table 6). We think that actual measurements will show an even greater difference between adults and juveniles.

Overall, adult Sharp-shins Hawks are about 1.3–1.8% larger than juveniles (Table 7). It is interesting to note that the percent increases in wing chord are exactly the same as the percent decreases in tail length. Increases in weight with age are actually greater than 5%, but weight

TABLE 6.
Estimated mean wing area and wing loading.

Age	Males: Wing area[1] (cm^2)	Males: Wing loading (g/cm^2)	Females: Wing area[1] (cm^2)	Females: Wing loading (g/cm^2)
Juv.	383.8	0.254	539.5	0.307
Adult	396.3	0.260	553.8	0.315

[1] Estimated by the formulae from Greenewalt (1962): wing area = (wing chord/0.62)^2/1.93. Estimates based on data in Table 2.

increases as the function of the cube of a linear dimension and the cube roots of the weight increase are only slightly higher, in percent, than the increases in wing chord.

Adults have longer and, probably, narrower wings providing a "cleaner" and more efficient aerodynamic design than that of juveniles. The heavier wing loading of adults both permits and obligates them to fly faster than juveniles. The presumed increase in the size of the flight muscles would result in a more powerful flight. The increase in weight and flight speed would combine to produce a greater striking force at prey. In short, adults are high performance, rapid, flying machines with increased striking force. These flight characteristics would also give adults an advantage over juveniles in intraspecific encounters.

Juveniles have shorter, broader wings, longer tails, and lighter wing loading values than adults. All these characteristics increase maneuver-

TABLE 7.
Ratio of adult-to-juvenile measurements.

		Sharp-shinned Hawk	Goshawk[1]
Tail	male	0.984	0.962
	female	0.987	0.978
Wing	male	1.016	1.012
	female	1.013	1.020
Weight	male	1.055	1.144
	cube root	1.018	1.046
	female	1.052	1.147
	cube root	1.017	1.046
Wing Area	male	1.033	1.026
	square root	1.016	1.012
	female	1.027	1.041
	square root	1.013	1.020
Wing Loading	male	1.024	1.117
	female	1.026	1.101

[1] Data from Mueller et al., 1976.

ability. This increased maneuverability is undoubtedly adaptive until the young birds acquire skills in flying, alighting, and particularly in the pursuit and capture of prey. Mueller and Berger (1970) have presented data which indicate that young Sharp-shins require considerable time to perfect predatory techniques.

The long tail of the juveniles also increases lift, thus requiring less energy than increasing the size of the wing which must be moved during flapping flight. The smaller flight muscles probably require less energy to function. The light wing loading may permit better utilization of updrafts, particularly those of low velocity. The light wing loading most likely permits juveniles to travel a given distance at a lower energy consumption than is true for adults. The softer, easily bent flight feathers of the juveniles are most likely an adaptation to reduce breakage in these relatively clumsy and inexperienced birds, rather than simply a result of more rapid feather growth as suggested by Amadon (in press). In short, juveniles appear to be adapted for greater maneuverability and lower energy consumption than adults. As skill in pursuing and capturing prey is attained, the birds can afford the higher speeds, greater striking force, and the higher energy consumption of the adults.

The preceding analysis of the functions of age-dimorphism is an elaboration and extension of that presented by Amadon (in press). We have been in close correspondence with Amadon on this problem for some time and the development of a concept has often been the result of several interchanges of ideas.

Goshawks show a greater relative decrease in tail length with age than do Sharp-shins. In both species the decrease is greater in males than in females. In Goshawks, females show a greater increase in wing length with age than males whereas the opposite is true in Sharp-shins. Weight increases with age are considerably greater in the Goshawk than in the Sharp-shin. The cube root of weight increase in Goshawks is more than twice as great as the increase in wing chord. Sharp-shins are true migrants, most of them flying at least hundreds of km every year, whereas Goshawks are usually permanent residents. It may be that those juvenile Goshawks that migrate have difficulty maintaining body weight, or that migrants are those which have been unable to compete with heavier, more successful birds in the normal range (see Mueller et al., 1977). Alternatively, the larger Goshawk may have to learn more about hunting than the smaller Sharp-shin. Goshawks probably could not survive by pursuing and capturing warblers; prey of size suitable for Goshawks is much less common than prey for Sharp-shins. The skills necessary for finding, capturing, and killing large prey probably require greater time and experience to achieve full proficiency than the skills necessary for capturing small prey. We have argued that the increased weight of adults is due to an increase in the size of flight muscles and that adults thus have a more powerful, rapid flight, and require more energy and food than juveniles. It appears that juvenile Goshawks can afford relatively less power than juvenile Sharp-shins.

It is interesting to note that Goshawks show a greater age-dimorphism than Sharp-shinned Hawks in both weight and tail length. The juvenile Goshawk is thus both relatively lighter in weight and longer-tailed than the Sharp-shinned Hawk, and has relatively more lift provided by the tail to carry relatively less weight. This could be taken as further evidence for the hypothesis that Goshawks require more experience than Sharp-shins to capture prey efficiently or as evidence for a related hypothesis. Larger birds have heavier wing loading values and must fly faster than smaller birds. More rapid (flapping) flight requires more energy. The larger Goshawk may thus be under greater constraints to conserve energy as a juvenile than the smaller Sharp-shin.

Several workers have noted changes in size with age of falconiform birds since Baird et al. (1905) showed that young Bald Eagles (*Haliaeetus leucocephalus*) have longer wings and tails than adults. Glutz et al. (1971) appear to be the only ones to have compiled measurements of juveniles from a larger number of species; most of this information is summarized by Amadon (in press) along with some original data. Glutz et al. (1971) present only means and extremes, and no measure of variance. Their sample sizes are often small, and some samples may be confounded by geographic variations and temporal variations caused by wear of feathers. With these reservations in mind, we tender a few generalizations below, along with numerous presumed exceptions.

In addition to the Goshawk and the Sharp-shin Hawk we have examined data on the Cooper's Hawk (*A. cooperii*), and in all three species juveniles have shorter wings and longer tails than adults. However, the European Sparrow Hawk (*A. nisus*) appears to show no change in wing length with age, and in the Levant Sparrow Hawk (*A. brevipes*), adults appear to have longer tails than juveniles. The available data suggest that juveniles of all species of Buteoninae have shorter wings and longer tails than the adults, with the exception of the sea eagles (*Haliaeetus*, data from three species) in which the juveniles have both longer wings and tails than the adults. Most Circininae also appear to fit the generalization of shorter wings and longer tails in juveniles than in adults, except possibly for the Marsh Harrier (*Circus aeruginosus*), in which juveniles might have both shorter wings and tails than adults. Juvenile Honey Buzzards (*Pernis apivorus*) seem to have shorter wings and tails than the adults, as do Red Kites (*Milvus milvus*). We know of no measurements of other species in either subfamily. Juvenile Bearded Vultures (*Gypaetus barbatus*) might have shorter wings and longer tails than adults; we were unable to find measurements of other Aegypiinae. The picture in the genus *Falco* is confusing. In several species the juveniles appear to have shorter wings and tails than the adults, in a few others the juveniles may have longer wings and tails than the adults, and in yet others there may be little or no difference between the ages. If all of the above variations stand the test of further data and statistical analyses, it will be extremely difficult to find an adaptive rationale for the differences. We are in the process of extracting data from our field notes for several species of hawks and falcons and hope to be able to eliminate some of the confusion.

The few data available suggest that young raptors do not weigh as much as adults. We know of no significant exception to this generalization. We suspect that all juveniles have lighter wing loading values, but we need many more data on wing areas and weights.

We have been searching the literature for age differences in size, and have found examples in a variety of orders, including Passeriformes. We encourage ornithologists to gather measurements on young birds, and for those that keep birds in captivity, or recapture individuals frequently, we suggest comparing measurements of the same individual as it ages.

SUMMARY

The sex of Sharp-shinned Hawks can be determined with near certainty by wing chord, weight, or tail length. The age of many adults (second year or after second year) can be determined by plumage or eye color. Adults have significantly longer wings, shorter tails, weigh more and have heavier wing loading values than juveniles. We believe that juveniles are adapted for greater maneuverability and lower energy consumption, and adults are adapted for high performance, greater speed, and striking power.

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